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Biochar production though combined solar drying & single chamber pyrolysis

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BIOCHAR PRODUCTION THROUGH COMBINED SOLAR DRYING & SINGLE CHAMBER PYROLYSIS

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Research Group:

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Problem Identification – Sustainability check

- **Fibrous Organic Wastes (FOW)** and **Municipal sewage sludge (MSS)** constitute the two largest urban organic waste fraction in newly industrialized economies (here: India).

- **Food spoilage** in veg and fruit markets due to lack of cold stores

- Current disposal or treatment is associated with **high CO_2 emissions** and costs as well as with **loss of resources**.

- Agriculture still accounts for more than 15% of the net GDP, employs millions, and affects the groundwater quality as well the nutrient cycle due to synthetic fertilizers application = **market and environmental impact**

Current Status of Waste „Handling“ in India

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Project: Idea – Structure and Partners

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Smart Cities integrated energy supply, carbon sequestration and urban organic waste treatment through combined solar sludge drying and pyrolysis

pyrasol

Indo-German 2 + 2 Consortium

Institute for Sanitary Engineering and Waste Management (ISAH)
Leibniz Universität Hannover,
Hannover, Germany

Ramky Enviro Engineers Ltd.
Hyderabad, India

ISAH
Leibniz Universität Hannover

CLRI

RAMKY GROUP
Towards sustainable growth

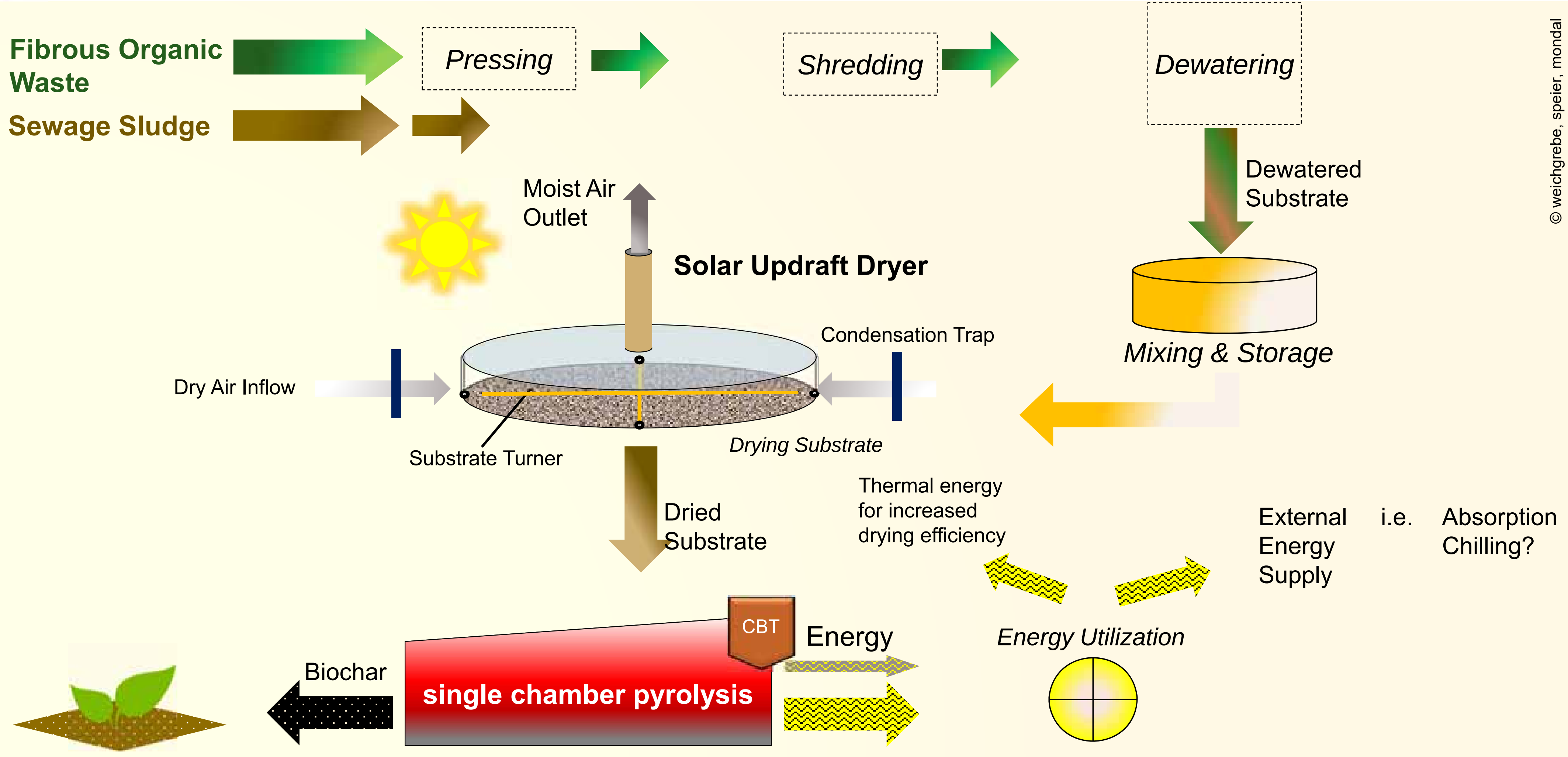
BIOMACON

Central Leather Research Institute (CLRI)
Council of Scientific & Industrial Research (CSIR),
Chennai, India

Biomacon GmbH
Rehburg, Germany

Approach and Process Flow

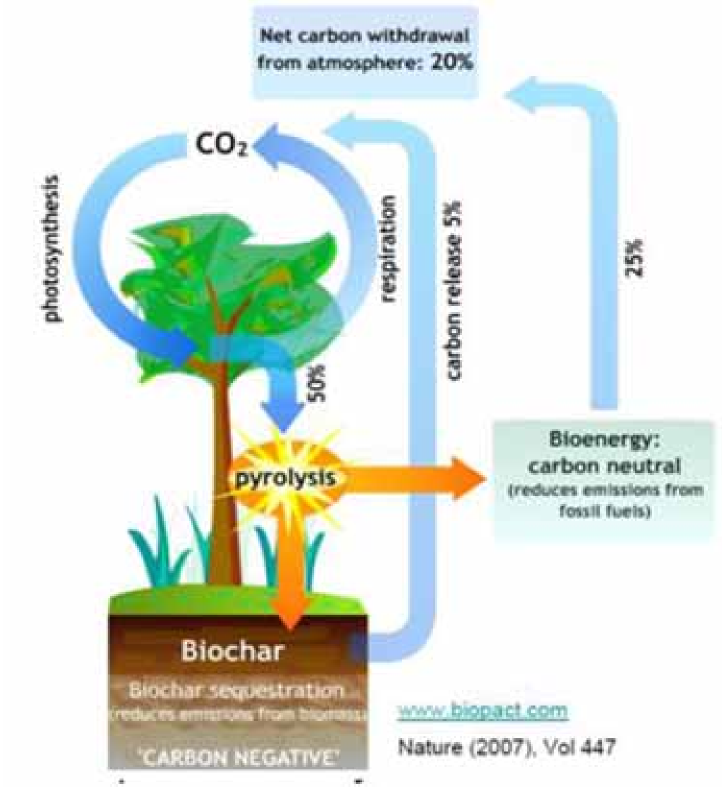
Project Approach



Integrated Approach

Sustainable Urban Organic Waste Management System

- Biomass valorization
- Negative CO_2 balance
- Energy self-sufficient
- Land reclamation / soil improvement
- Complete **pathogen removal**
- **Stable operation and handling**



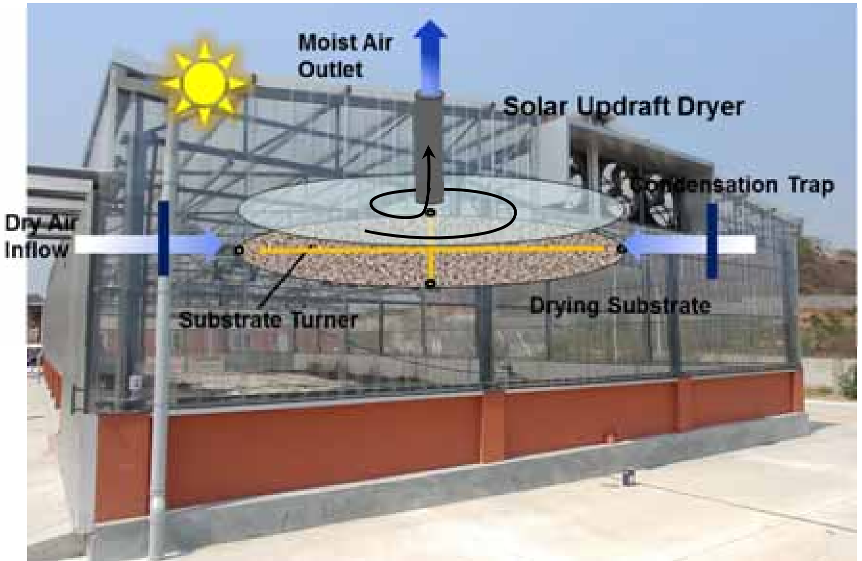
Innovation Solar Drying

Solar Updraft Dryer

- Natural ventilation and air mixing
  through **vortex chimney effect**
  - ➢ No mechanical ventilation systems required

- Drying and pathogen removal with solar energy
  - ➢ **Reduction of energy expenses**

- **Co-drying** of mixed fibrous organic waste and sewage sludge incl. use of pyrolysis exhaust heat, and condensation trap for inlet air
  - ➢ Minimzing of land use and increased drying efficiency



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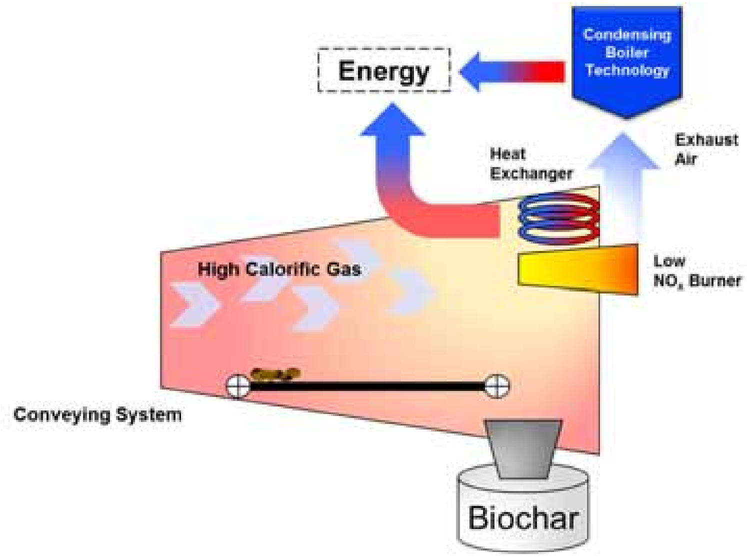
Project Approach

Innovation Pyrolysis

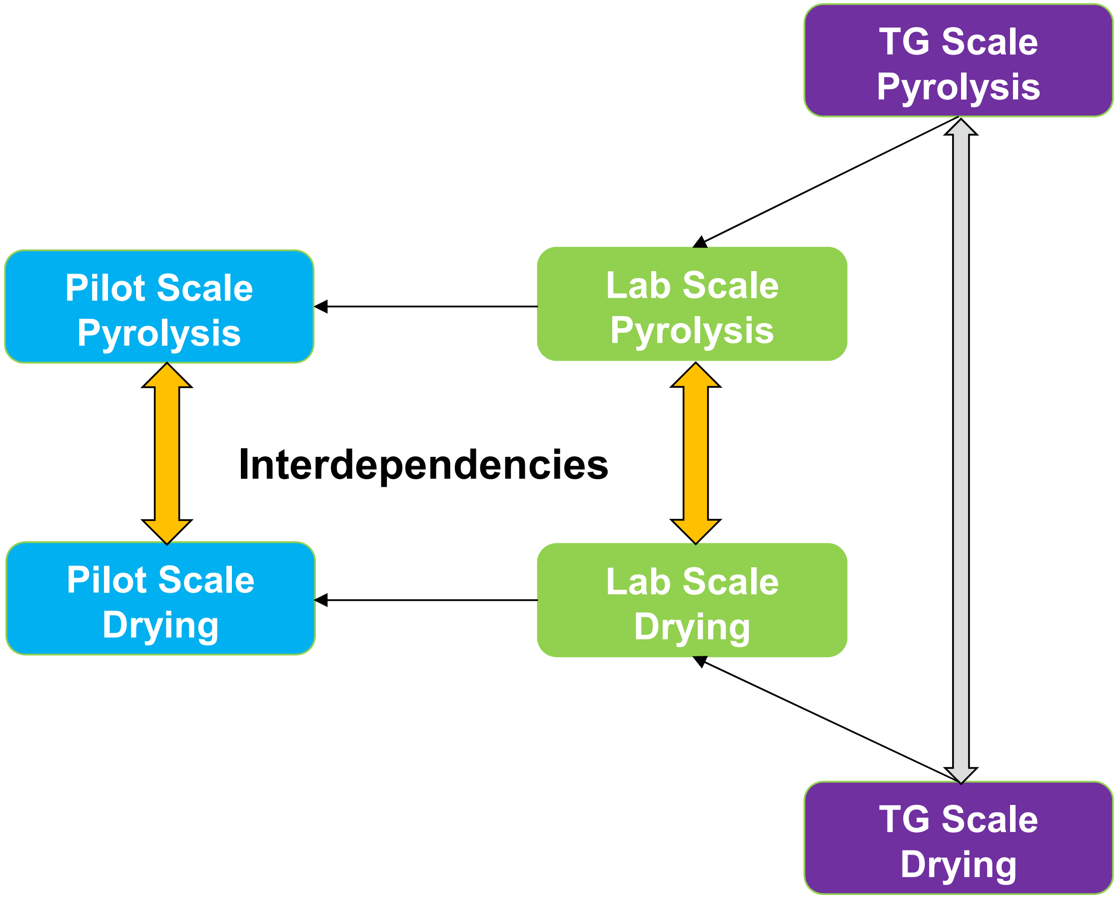
Single Chamber Pyrolysis

- Condensing Boiler Technology
  - Recovery of condensation energy
  - Increased energy efficiency and market competitiveness for the pyrolysis process
  - Higher energy output to cover growing energy demand in Smart Cities



Project Approach

Determining Scaling Effects / Parameters



Lab Scale Experiments

Lab Scale Solar Dryer

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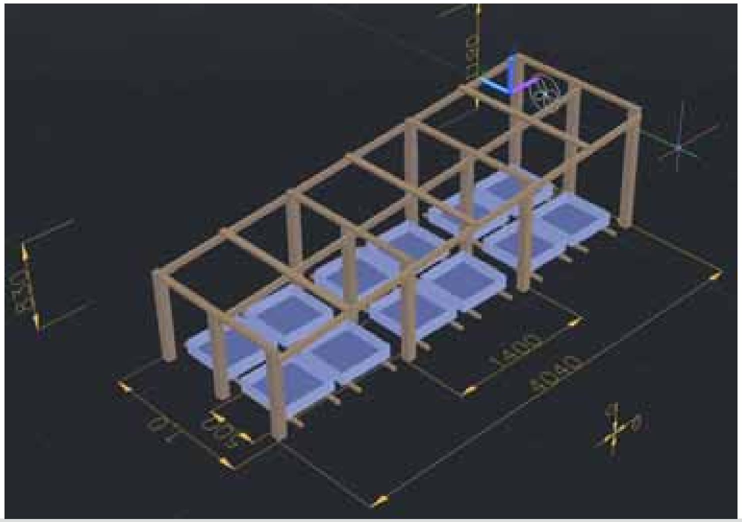

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Lab scale dryer construction

- UV protected 6mm twin wall PC sheet
- Flooring is 25mm rock wool sandwiched
- Automated operation with T, humidity, Radiation sensors

Measurement Parameters

- Moisture loss over drying time ($^{\mathrm{dm}}/_{\mathrm{dt}}$)
- Temperature profiles of the substrate
- Residence time (drying period) in the dryer
- Water content (WC), Ignition loss (IL) and Organic Dry matter content (oDM) of dried product
- pH and conductivity of condensate
- Calorific value of the dried substrate (3rd party labs)

Lab Scale Experiments

Beside TGA we use Lab Scale Pyrolysis

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Materials

- Oven dried Sewage Sludge, Banana Peduncle and AD Digestate

Method

- Pyrolysis at linear heating rates of 10 and 15K/min to 500°C with holding time of 45 and 90 minutes.
- Nitrogen purge of 150 ml/min
- Weighing pre- and post pyrolysis
- Condensation of bio-oil through chilling unit, and removal with acetone
- Storage of biochar
- Total experiments: 64 (@2/day) - singlets

Semi Labscale Pyrolysis (Gasification) - Chantico

https://www.chantico-terrassenofen.de/

© foto: weichgrebe

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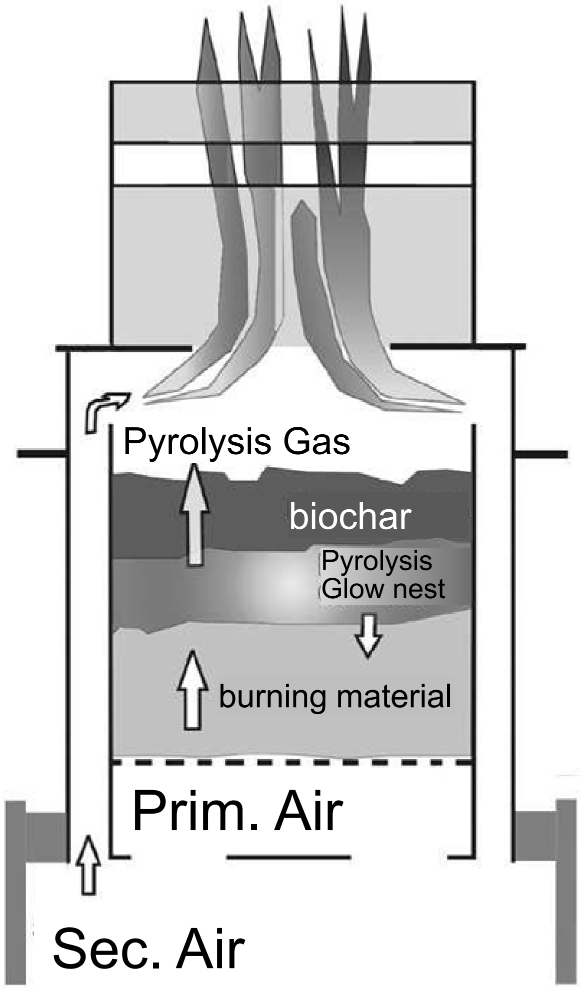

modified from chantico terrace oven´s manual https://www.chantico-terrassenofen.de/

Pilot/Techn. Scale Experiments – BIOMACON 24 kW

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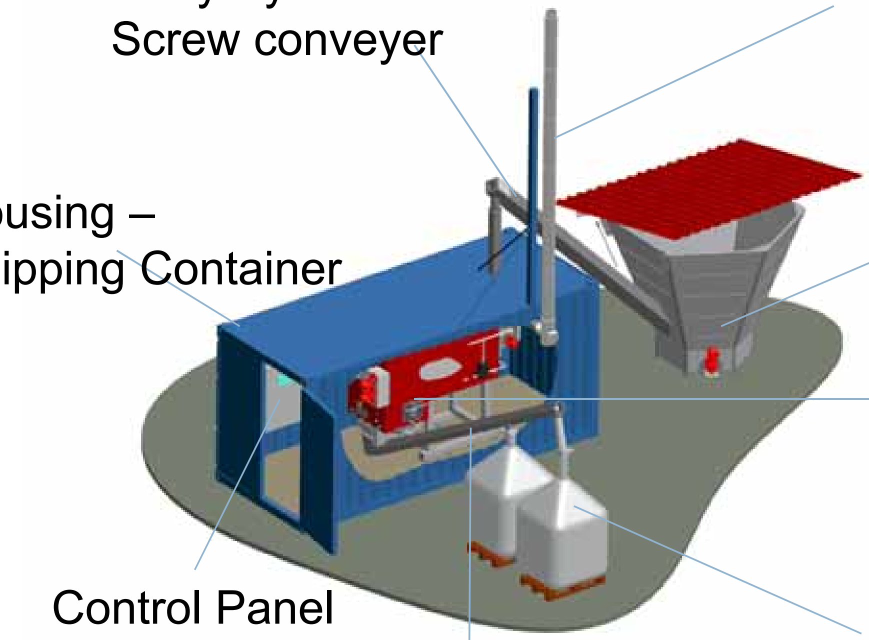
Single Chamber Pyrolysis



www.biomacon.com

Project Status

Solar Updraft Drying Model

Radiation – Biodrying – Convection

Drying rate

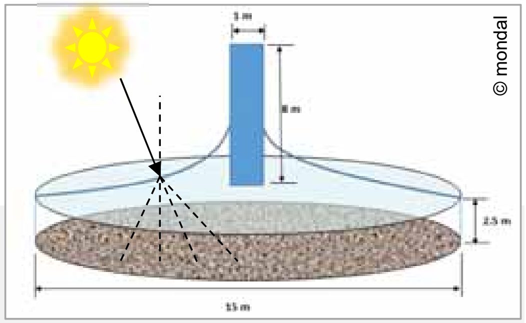
$$r_{ev} = \rho_{air} \cdot q_v \cdot (\varphi_{out} - \varphi_{in}) = \rho_{air} \cdot q_v \cdot \Delta\varphi \quad \left[\frac{\text{kg (water)}}{\text{m}^2 \cdot \text{h}}\right]$$

$$\Delta\varphi = \alpha \prod_{j=1}^{p} (P_j + \beta_j)^{\gamma_j}$$

$$= 1.96 \cdot 10^{-11} \cdot [(R_{amb} + 1100)^{2.322} \cdot (T_{amb} + 13.0)^{1.292} \cdot (q_v)^{-0.577} \cdot (q_m + 0.0001)^{0.013} \cdot (DSC_{in} + 0.26)^{-0.353}]$$

Drying area

$$A_d = \frac{1}{\bar{E}} \cdot m_{wet} \cdot \left(1 - \frac{DSC_{in}}{DSC_{out}}\right) \quad [m^2]$$



Air velocity in the chimney inlet

$$v_{chim} = \left(-\frac{1}{6} \cdot \frac{A_1 - \sqrt{3}\sqrt{A_2}}{c_{air} \cdot \rho_{air} \cdot T_{amb} \cdot {D_{chim}}^2 (1 + \xi)}\right)$$

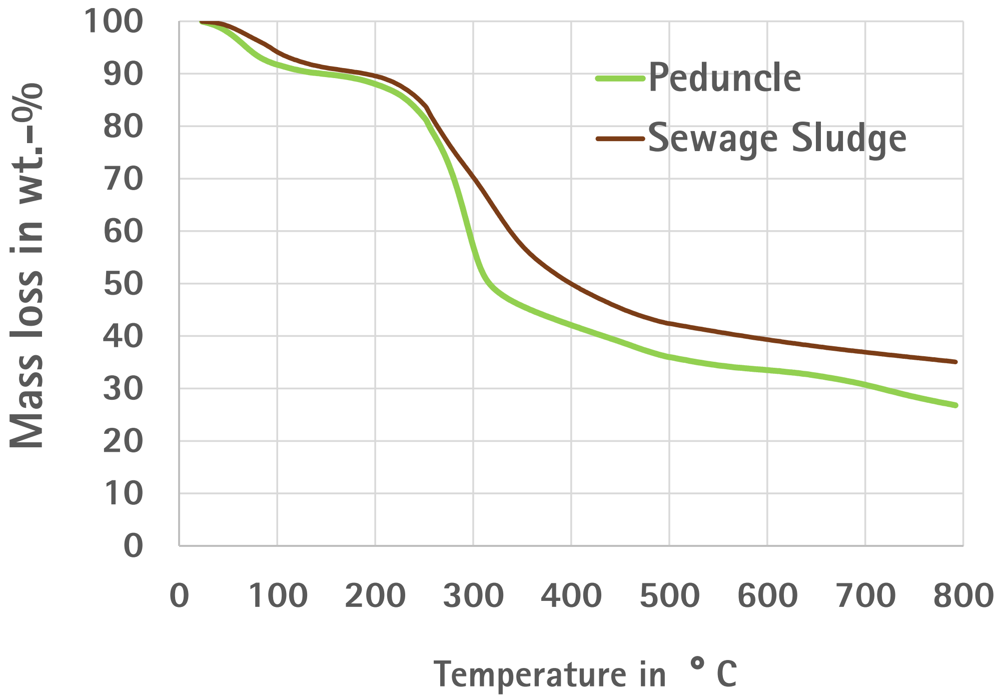
$$A_1 = 3 \cdot \beta \cdot {D_{coll}}^2 \cdot T_{amb} \cdot (1 + \xi)$$

$$A_2 = {D_{coll}}^2 \cdot T_{amb} \cdot (1 + \xi) \cdot \left(\begin{array}{c} (T_{amb} \cdot (1 + \xi) \cdot g \cdot h_{chim} \cdot \alpha \cdot G \cdot \beta) \cdot \beta \\ +4 \cdot \sqrt{3} \cdot \sqrt{2} \cdot \sqrt{A_1} \cdot c_{air} \cdot \rho_{air} \cdot {D_{chim}}^2 \end{array}\right)$$

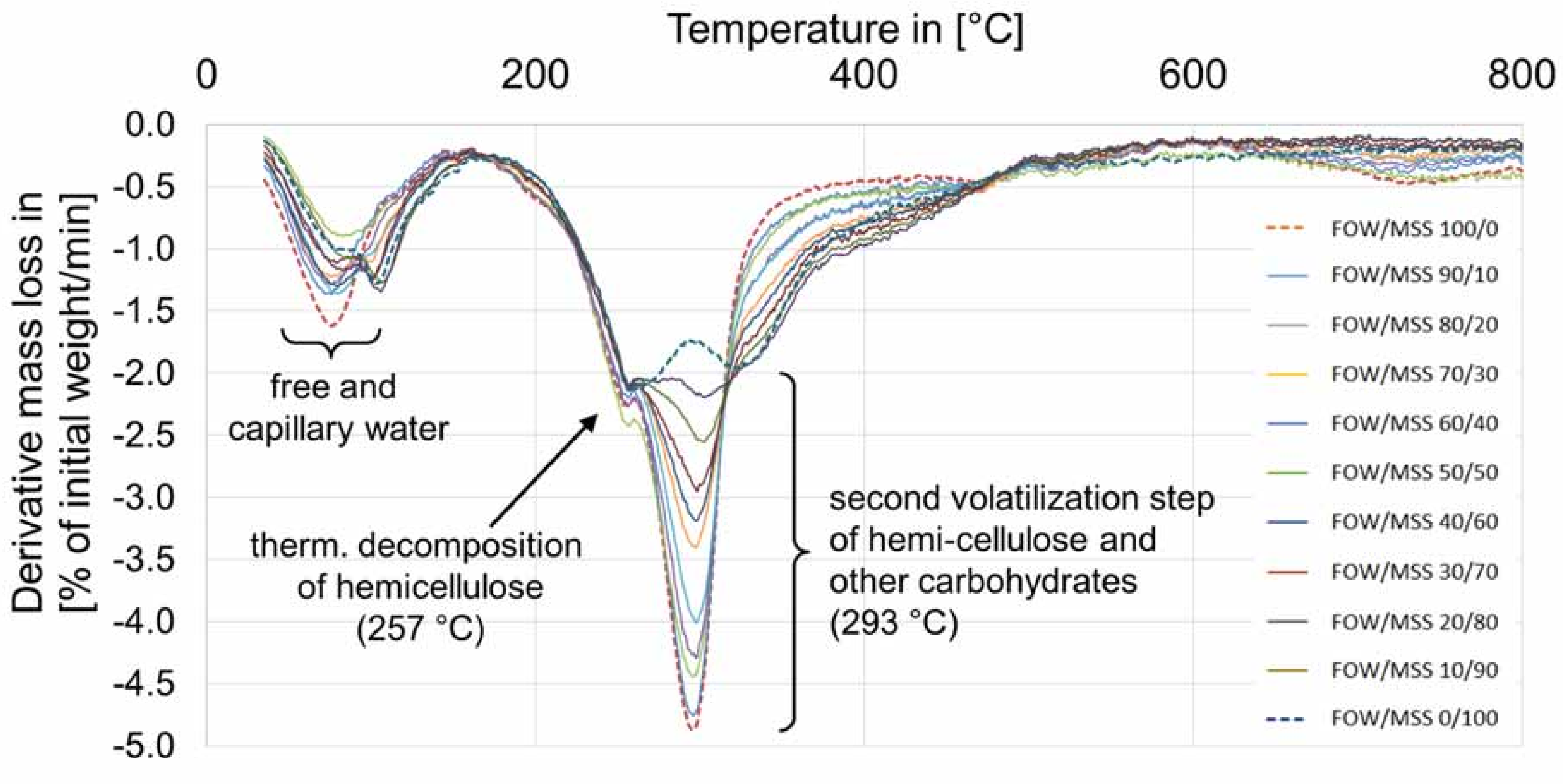
Diameter of the solar collector $D_{coll} = 2 \cdot \sqrt{(A_d + A_{chim})/\pi}$

With,
ρ_{air} - air density in [kg/m^3]
$\Delta\varphi$ - humidity ratio difference [%]
R_{amb} – amb. solar radiation [W/m^2]
T_{amb} – amb. temperature [K],
q_v - exhaust ventilation rate [m^3/m^2·h]
q_m - air mixing rate [m^3/m^2·h],
$\bar{E}$ – avg. evaporation rate [kg (water)/m^2·a],
m_{wet} - wet substrate input [kg/a]
DSC_{in} - dry solid content at the beginning of drying period [%]
DSC_{out} - dry solid content at the end of drying period in [%].
v_{chim} – max. vertical air velocity in the chimney inlet [m/s],
c_{air} - specific heat capacity of air [1,005 J/kg·K],
D_{chi} - diameter of the chimney [m],
ξ - friction loss coefficient [-],
α - effective solar absorptivity of the material in the collector [-],
β - thermal loss coefficient [W/m²·K],
g - gravitational acceleration [m/s²],
h_{chim} - height of the chimney [m]
D_{coll} - diameter of the collector [m],
A_{chim} - cross section area of the chimney [m²], and
G - global solar radiation [W/m²].

TGA Analysis: Mass Loss of single fractions



TGA Analysis: Rate of Mass Loss for Mixtures



Thermogravimetric characteristics of different substrate mixtures

The shares of peduncle (FOW) and MSS are given in percentages

Project Outcomes

Material Flow Model: Example Estimation with STAN2©

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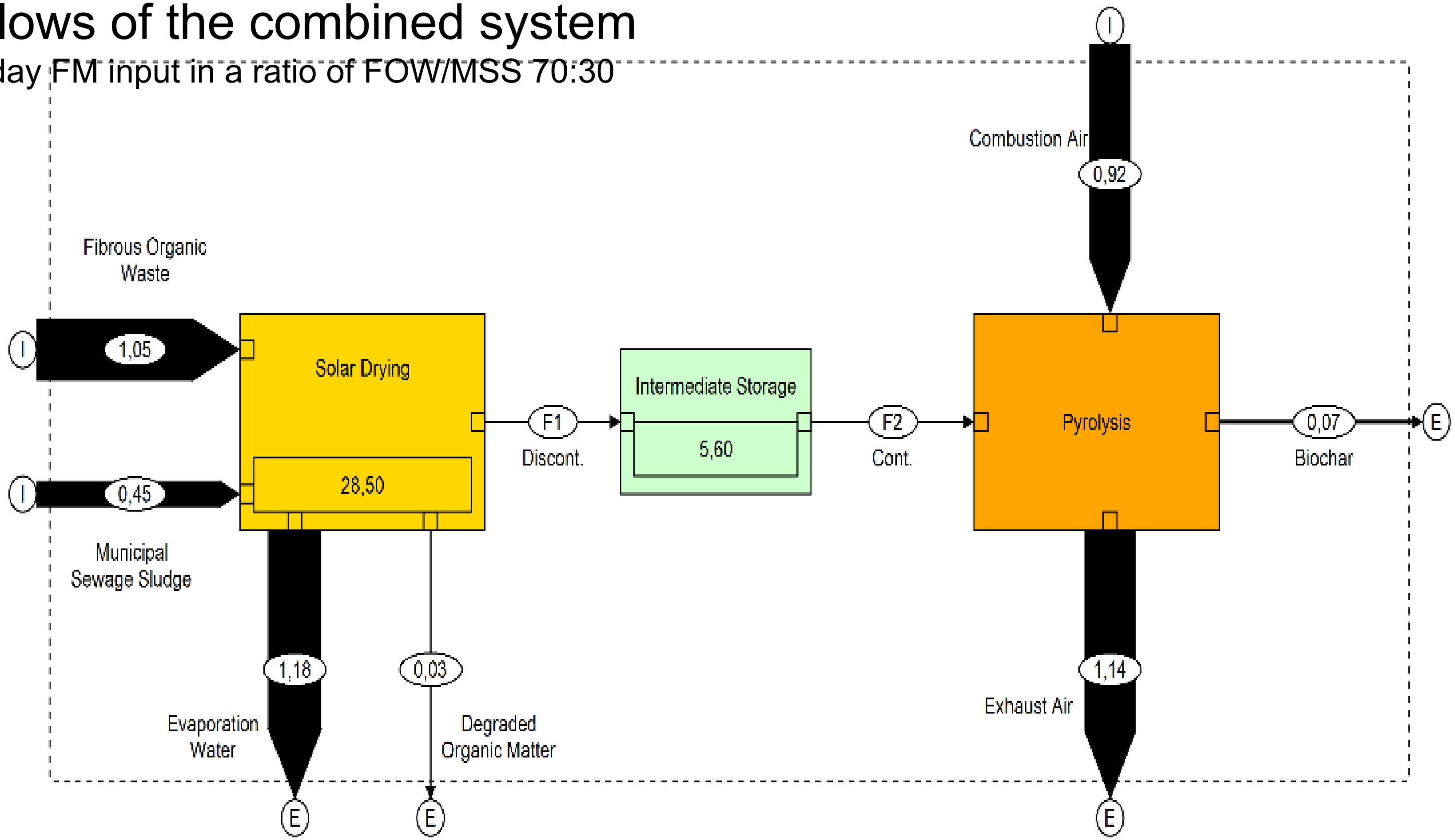
Material flows of the combined system

- for 1.5 tons/day FM input in a ratio of FOW/MSS 70:30



Pyrolysis Characteristic Analysis

Project Outcomes

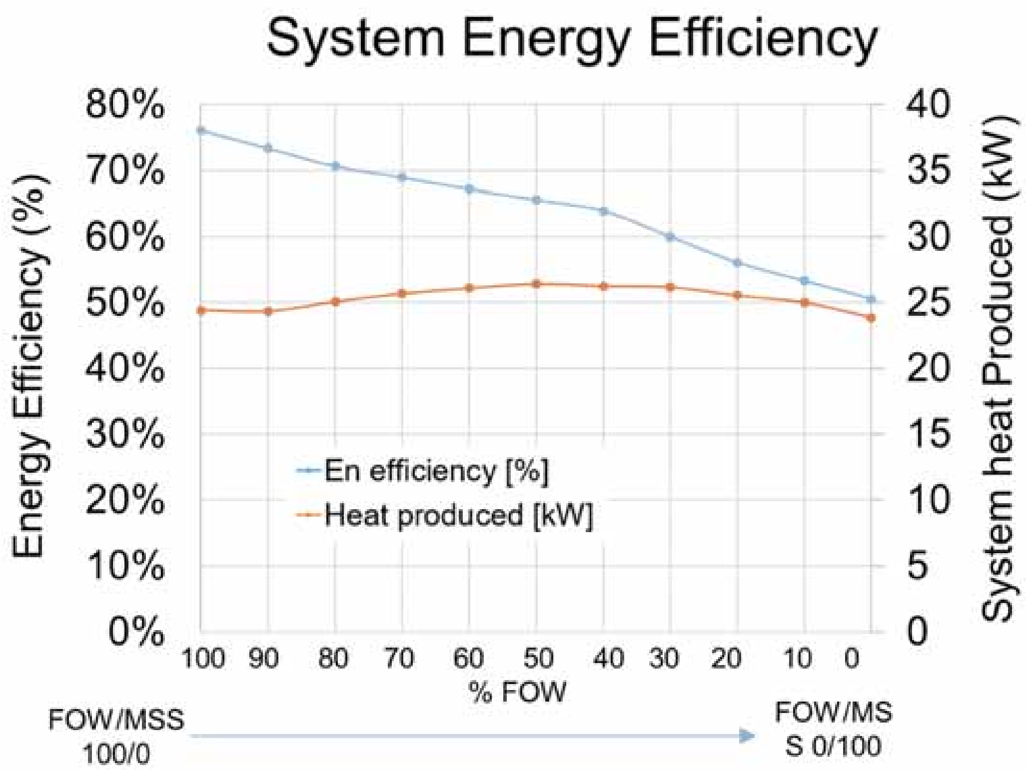
Pyrolysis process characteristics with varying FOW/MSS ratios

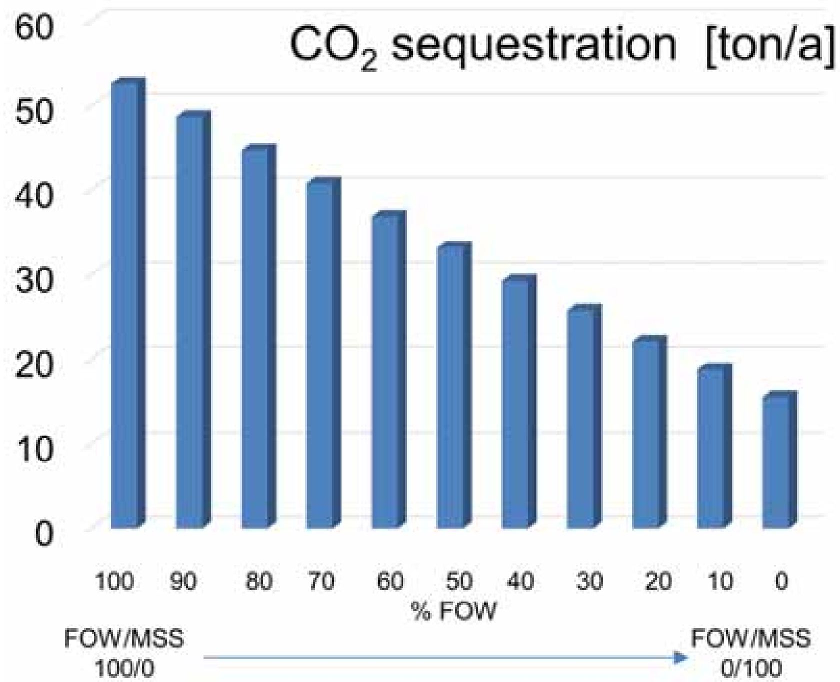
FOW/ MSS	[wt.-%]	90/10	80/20	60/40	50/50	40/60	20/80	10/90
Biochar	[kg/d]	116.1	111.0	101.0	96.0	91.0	81.0	75.9
Th. Energy	[MJ/d]	1668.1	1643.5	1594.9	1570.7	1546.7	1499.3	1476.1
CO_2 Seq.	[kg CO_2/d]	165.3	158.2	143.9	136.8	129.6	115.3	108.2
Exhaust Air	[m^3/d]	1155.0	1127.3	1073.4	1047.5	1022.4	975.5	954.5

System Analysis

Project Outcomes

System efficiency and CO_2 sequestration





Mass & Energy Flows: Example Estimation

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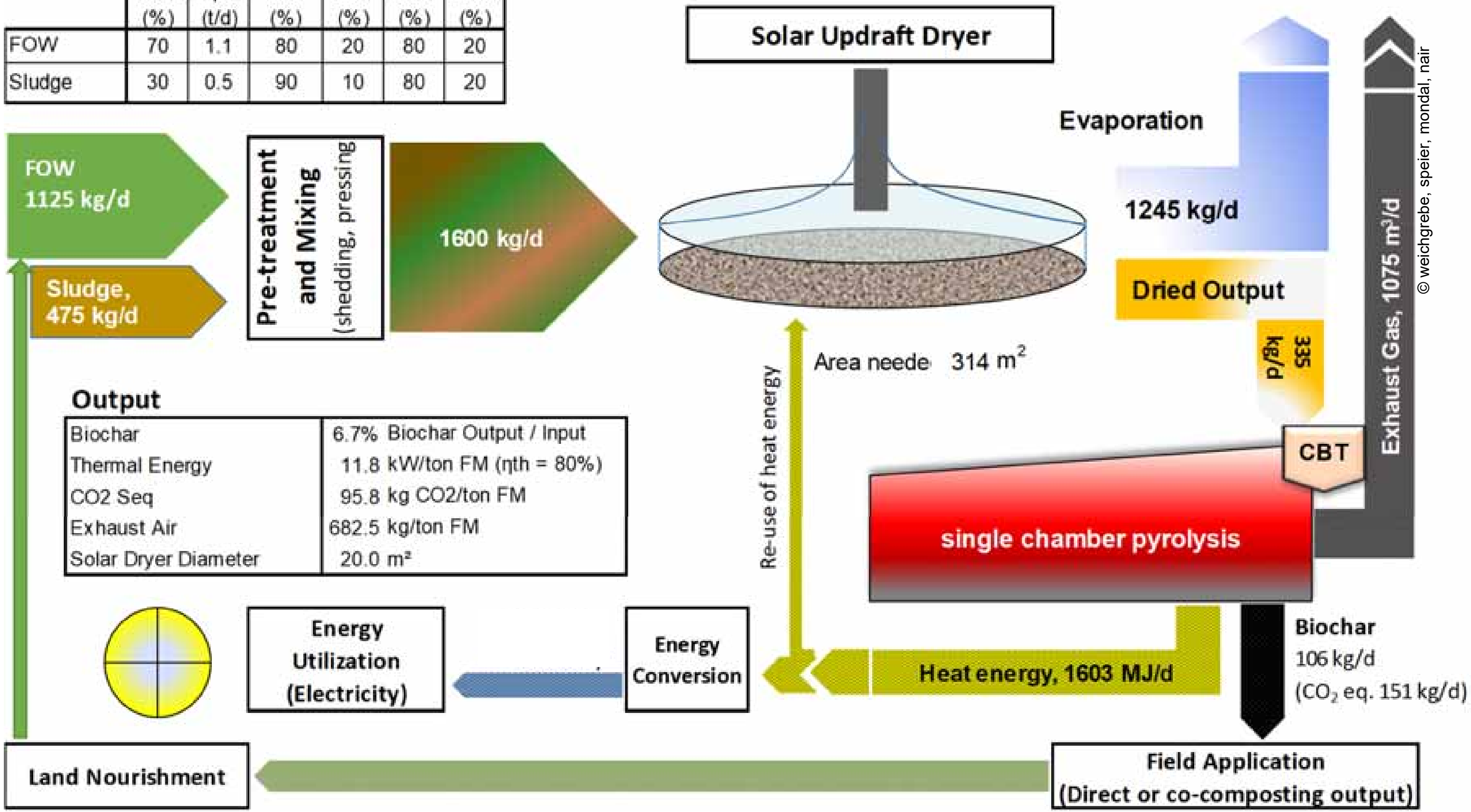
Input substrate

	Ratio (%)	Input (t/d)	WC (%)	DM (%)	oDM (%)	mDM (%)
FOW	70	1.1	80	20	80	20
Sludge	30	0.5	90	10	80	20

Output

Biochar	6.7% Biochar Output / Input
Thermal Energy	11.8 kW/ton FM (ηth = 80%)
CO2 Seq	95.8 kg CO2/ton FM
Exhaust Air	682.5 kg/ton FM
Solar Dryer Diameter	20.0 m²



Fresh Substrate
1600 kg/d

Dried Substrate
335 kg/d

Biochar
106 kg/d

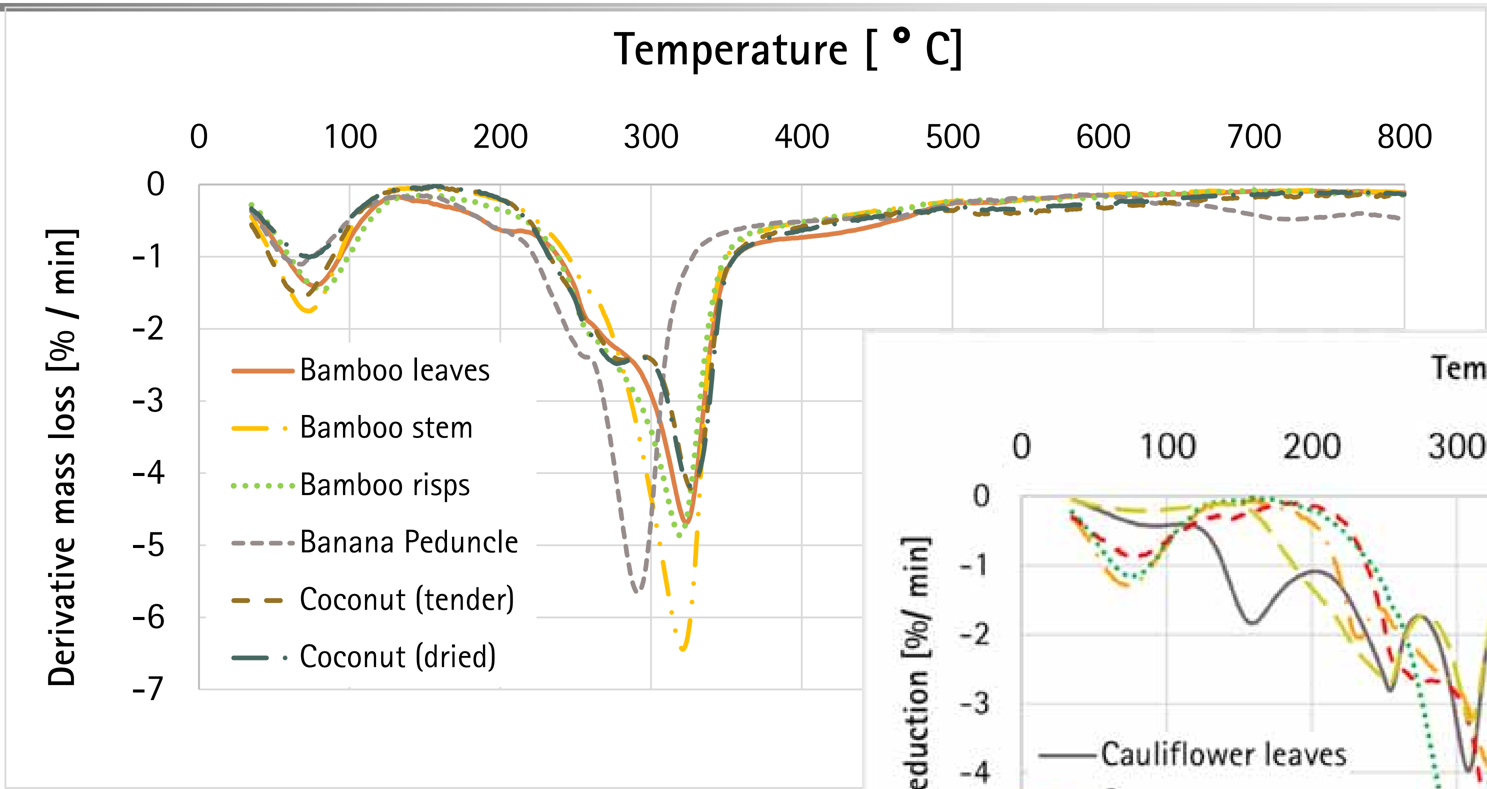
Energy
1603 MJ/d
280 kWh/d
=
11.8 kW/t FS

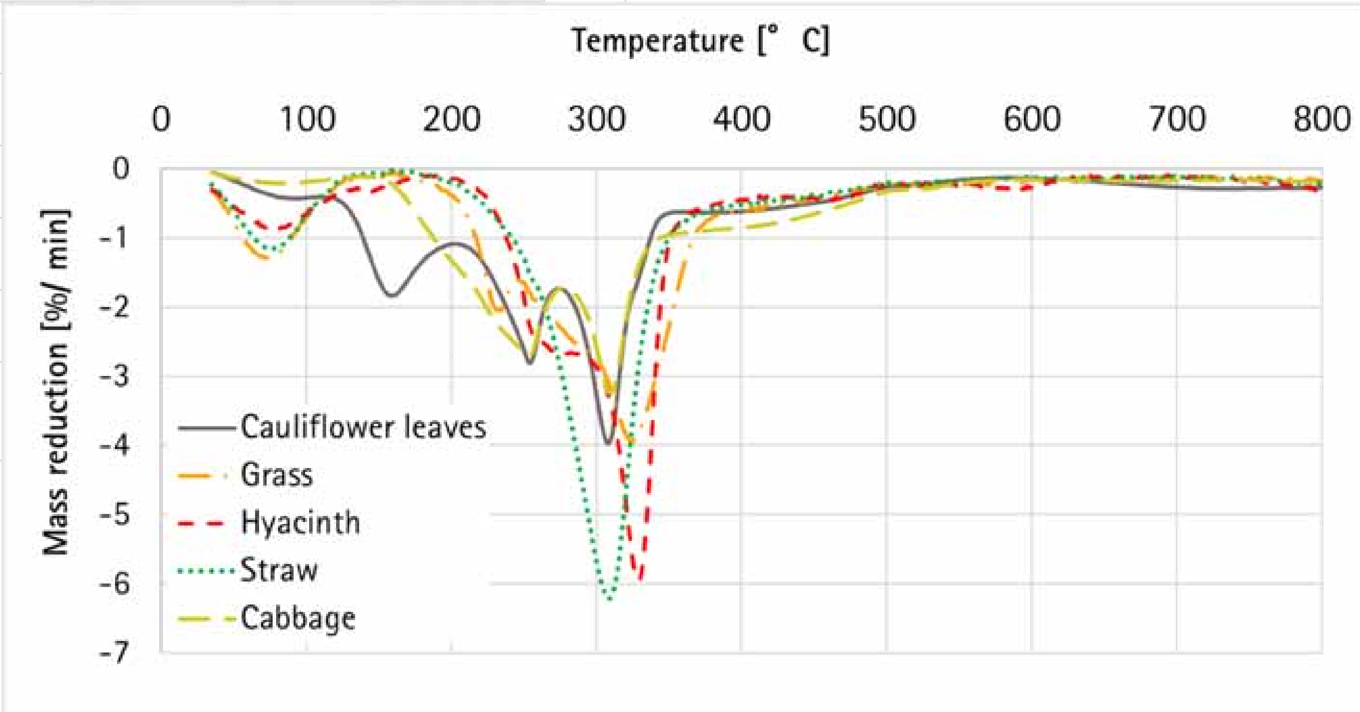
Further Steps

Way Forward

- Incorporation of other fibrous organic wastes like **coconut shells** into drying and pyrolysis
- Elemental analysis and fiber analysis of substrates used for drying and pyrolysis
- Determining the **Scaling effects and parameters**
- Possibility of **extrapolating the chimney height** of the SD pilot plant from the lab-scale experiments
- Determination of the lab-scale solar drying models
- Pilot scale trials
- Selection and comparison of **Absorption Chilling** and **Sterling Engine**

Pyrolysis: Lab investigation





LCA Model devlopment: PYRASOL Process with umberto® LCA+

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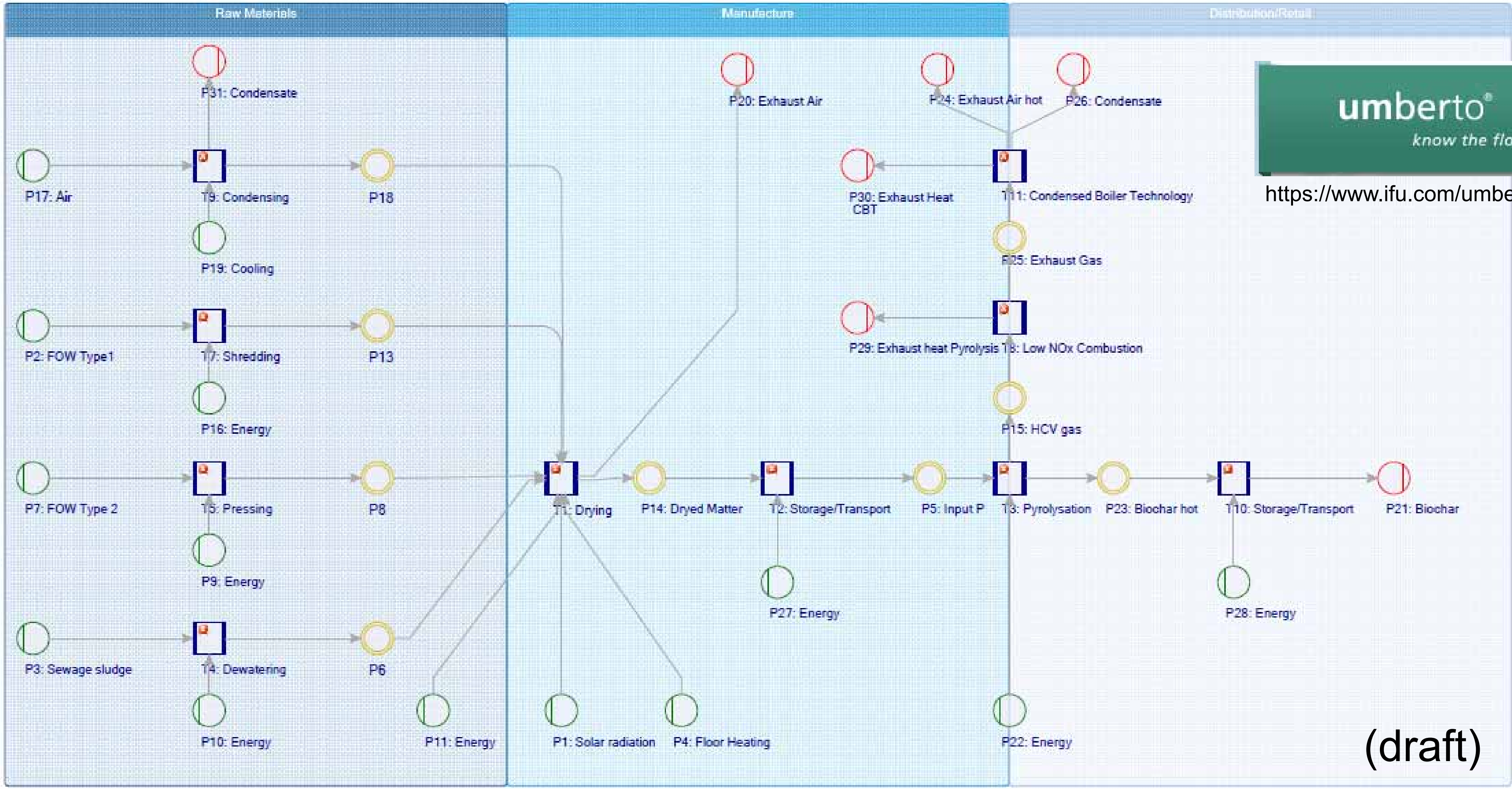

https://www.ifu.com/umberto/

Thank you for your attention!

Acknowledgement

Project Partners

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CLRI

RAMKY

BIOMACON

funded by

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Bundesministerium für Bildung und Forschung

IGSTC
INDO-GERMAN SCIENCE AND TECHNOLOGY CENTRE

Indo-German
2 + 2 Project

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Biochar Production through Combined Solar Drying & Single Chamber Pyrolysis

Dirk Weichgrebe, Moni M Mondal, Christopher Speier, Rahul R Nair

1. Problem Statement

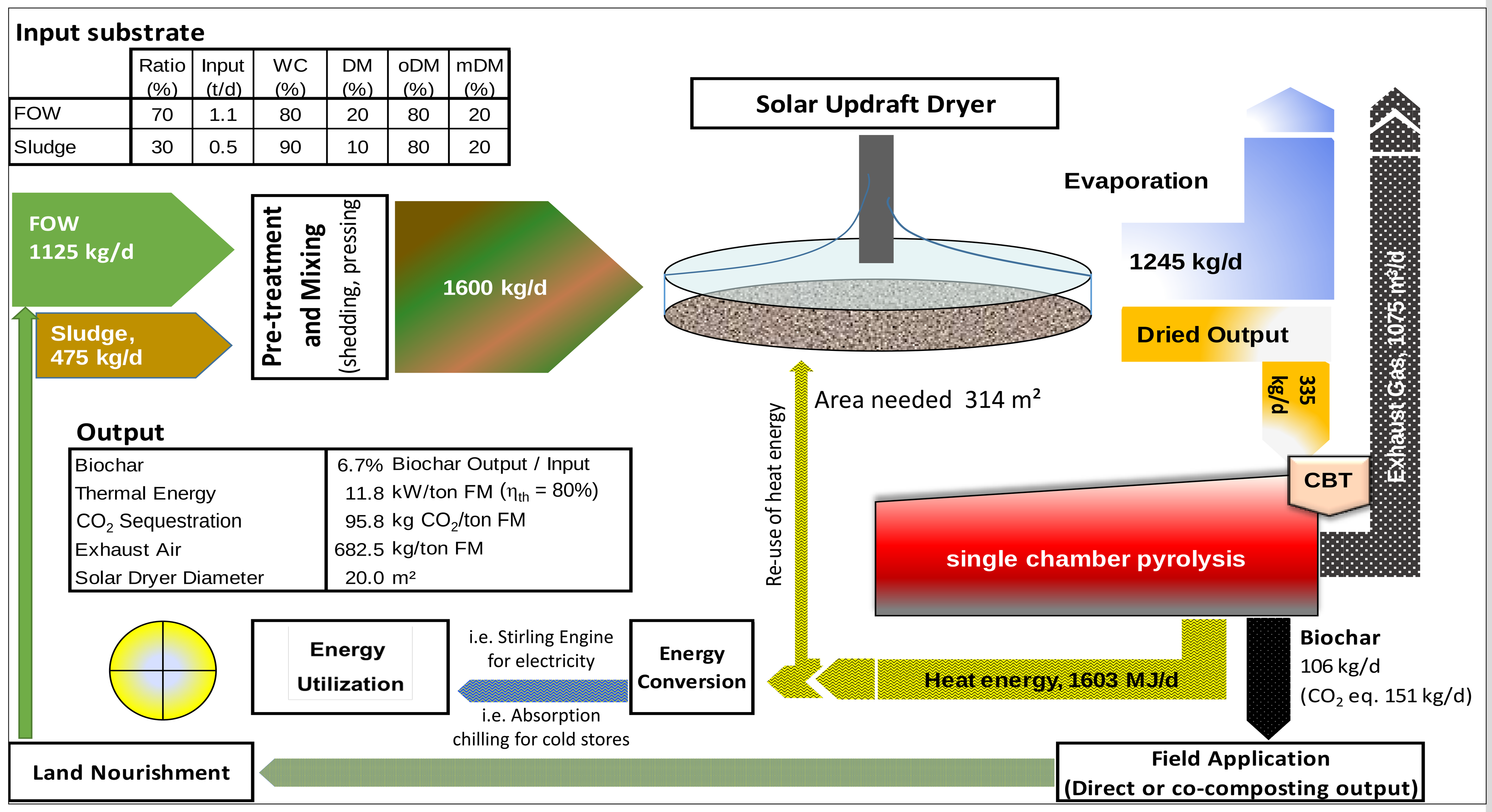
In newly industrialized economies

- agriculture still accounts for more than 15% of the net GDP, employs millions, and affects the groundwater quality as well the nutrient cycle due to synthetic fertilizers application.
- Fibrous Organic Wastes (FOW) and Municipal Sewage Sludge (MSS) are the two largest fractions of urban organic waste, whose disposal or current treatment is associated with CO_2 emissions, high costs or loss of resources.

2. Scope

- **Sustainable management** of fibrous organic waste (FOW) and dewatered municipal sewage sludge (MSS) in urban areas of newly industrialized economies along with a **negative CO_2 balance** and **biochar production**.
- Feasibility, demonstration and math. modelling of a combined treatment approach for both substrates comprising solar drying (SD) + single chamber pyrolysis (PYR).
- Mass and energy flow analysis on the basis of material and process investigations as well as balance projection for the city of Chennai, India.

3. Approach and Process Flows incl. mass & energy balance



Calculation basis:

Input $m_{wet,d}$ = 1,600 kg/d fresh matter, mixed FOW and MSS with ratio of 70/30.

Calculation results:

- 335 kg/d dried matter (20 wt.-% water) after SD
- 106 kg/d biochar after SD and PYR equivalent to:
  $m_{CO2,d}$ = 151 kg/d of sequestrated CO_2, and
  $E_{th,d}$ = 18.9 kW/d thermal energy.
- marketable products:
  66.3 kg biochar/ ton substrate and
  11.8 kW heat energy/ton substrate

Potentials of heat energy utilization:

Absorption chilling at vegetable markets for cold storage facilities to avoid fruit spoilage

Floor heating of the SD for enhancing the drying

4. Results

Pyrolysis process characteristics with varying FOW/MSS ratios

FOW/ MSS	[wt.-%]	90/10	80/20	60/40	50/50	40/60	20/80	10/90
Biochar	[kg/d]	116.1	111.0	101.0	96.0	91.0	81.0	75.9
Th. Energy	[MJ/d]	1668.1	1643.5	1594.9	1570.7	1546.7	1499.3	1476.1
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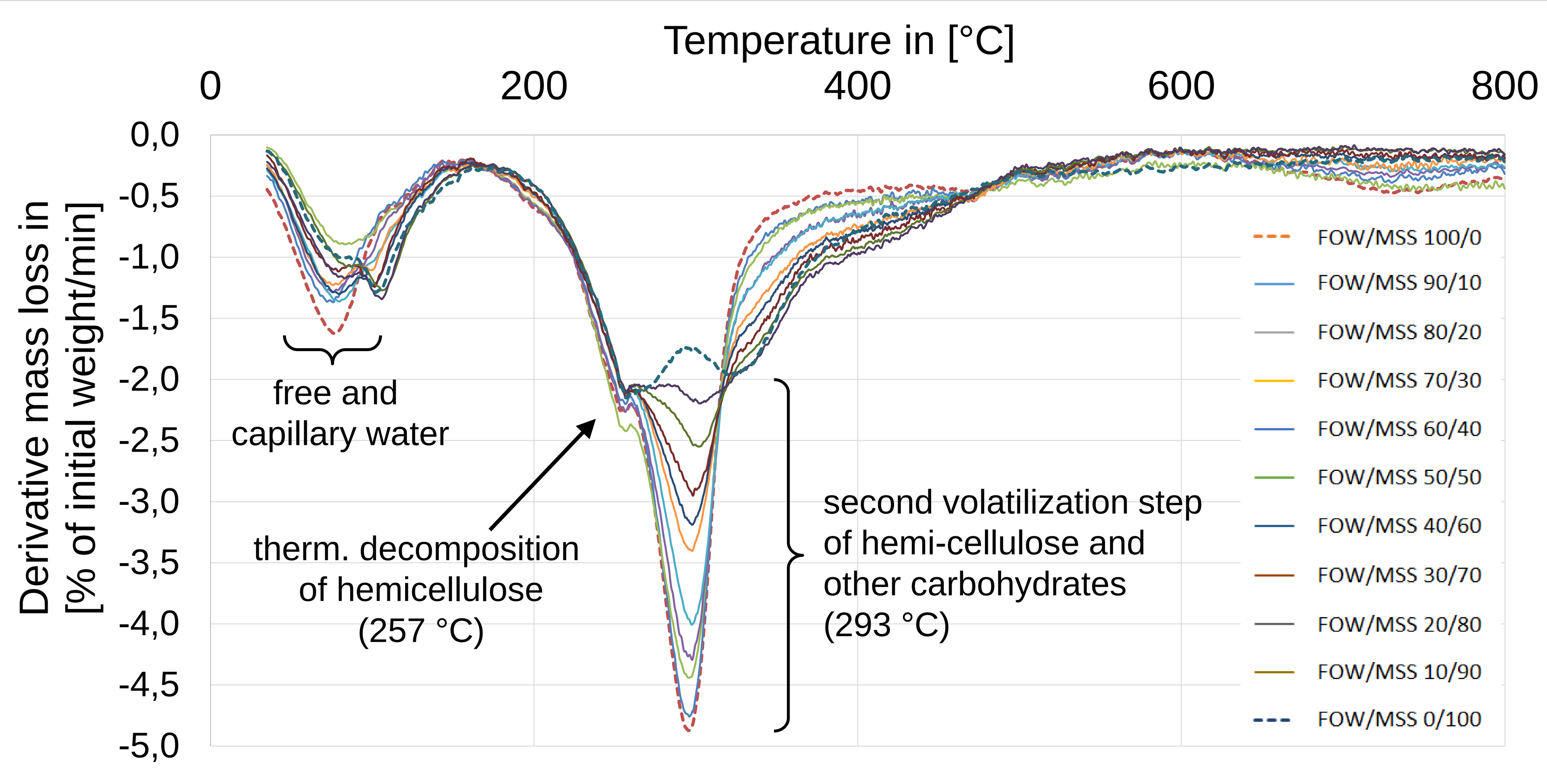
Exhaust Air	[m³/d]	1155.0	1127.3	1073.4	1047.5	1022.4	975.5	954.5

High FOW content results in high biochar production:
FOW/MSS 90/10 => 20.8 % of dried matter input
FOW/MSS 10/90 => 4.7 % of dried matter input

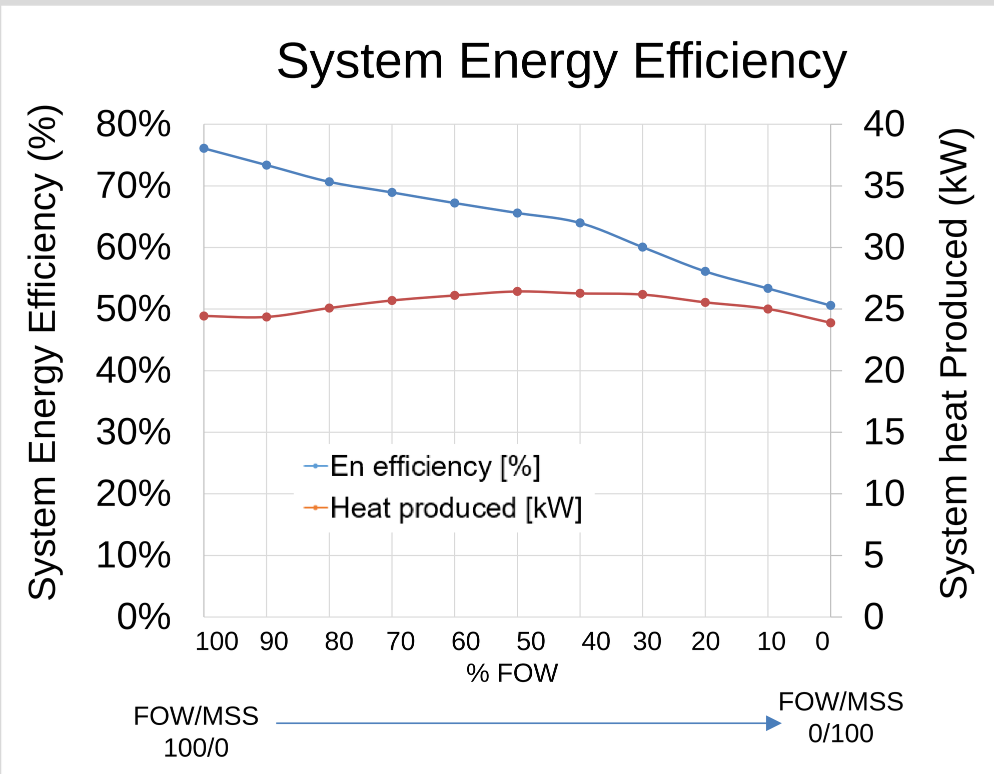
Overall system efficiency degreases with increasing share of MSS:

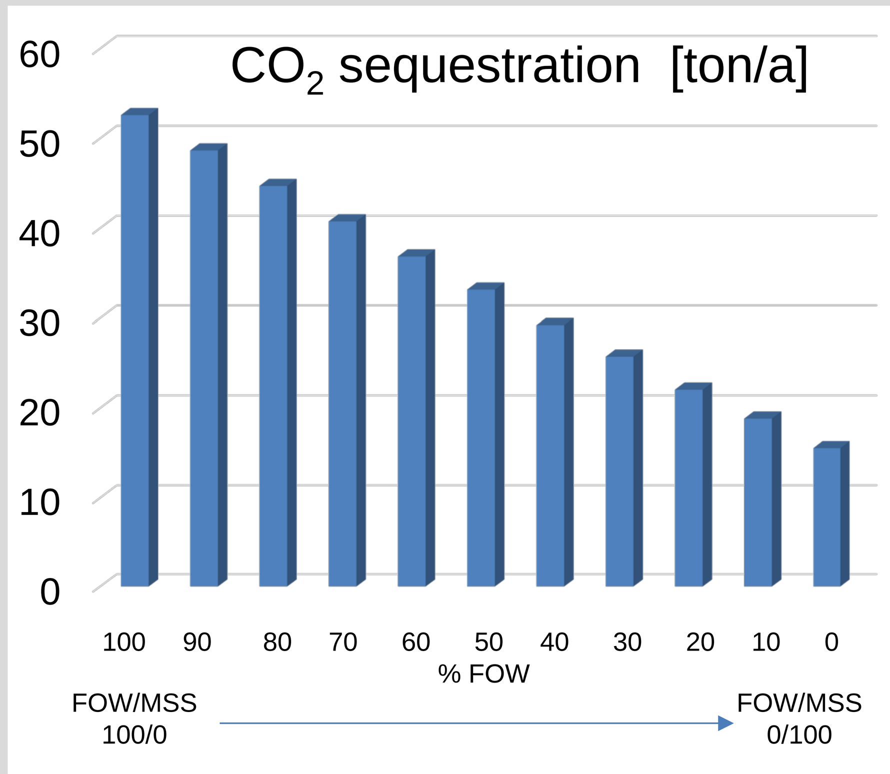
- **maximum energy efficiency** $\eta_{th\ E,\ sys}$ = 76% at FOW 100 % share, 52 ton CO_2/a sequestrated and 24 kW heat provided,
- **CO_2 Sequestration** decreases with increasing MSS share, 90.82 kg/d CO_2 sequestrated at max. system heat produced (excl. fossil fuel substitution potential of heat produced)

Thermogravimetric characteristics of different substrate mixtures



Determination of the best scenario based on Energy Efficiency





5. Conclusions and outlook

- ✓ Sustainable & **CO_2-negative solution** for urban organic waste
- ✓ CO_2 sequestration along with biochar application in soil
- Enrichment of organic content in soil and improvement of soil resilience, e.g. through increased water retention capacity, are yet to be investigated.
- Proof of the Condensing Boiler Technology for the pyrolysis unit

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Bio-Char II: Production, Characterization and Applications;
An ECI Conference, Cetraro (Calabria), Italy, September 15th–20th, 2019

Project: pyrasol

Project Partners: Leibniz Universität Hannover, BIOMACON, CLRI, RAMKY Group

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